TOWARD A MORE PRECISE CONCEPT OF INFORMATION TECHNOLOGY

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Toward a More Precise Concept of Information Technology

J. Yannis Bakopoulos

ABSTRACT

The concept of information technology is at the core of MIS research, yet little effort has been expended to provide a definition that allows us to compare and contrast systems and generalize results across studies, and that is valid from an organizational and behavioral as well as an information theoretic point of view. In this paper we attempt to derive such a definition starting from the construct of bounded rationality, and we explore the significance of this effort for the MIS discipline.

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1. Introduction

The concept of Information Technology is central to the Information Systems discipline. The diverse capabilities of this technology and its pace of evolution are at the core of the I/S management problem. In view of this centrality, it is surprising that we do not have a definition or characterization of information technology in terms that allow us to compare and contrast systems and generalize results across studies. In the absence of a well-developed MIS perspective, computer science tends to fill the gap by succinctly imposing its own language and definitions, which often prove inadequate for MIS research, especially when organizational or behavioral issues are of importance. In other words, we have not been able to create an adequate language around this concept, and the consequences include three major shortcomings:

- We have difficulty generalizing our research results beyond the narrow circumstances in which they are observed. Without an appropriate language for constructing theories, general models cannot be built and evaluated [2, 3]. We are thus left with a multitude of case studies, frameworks and fragmented approaches, but few theories.

- We cannot easily operationalize variables related to information technology, with resulting measurement problems that inhibit the testing of our theories. Untested (or, even worse, untestable) theories are only conjecture.

- Finally, this definitional problem inhibits the evolution of an established reference discipline, which would enrich the scope and enhance the theoretical validity of our research [13].

We can long debate the causes for the lack of a broadly valid definition of information technology. Typical arguments could include the lack of familiarity of I/S researchers with organizational and strategic disciplines, the limited interest of researchers in these fields on the effects of information technology which they saw up to now as little more than a minor curiosity, and inadequate

focus on related research efforts on the part of MIS researchers. The important issue, however, is to identify the steps that have to be taken to remedy this situation and to move toward a more precise definition and a working characterization of the concept of information technology. Both concepts of "information" and "technology" are backed by a long evolution, so it seems that we have to pay more attention to the ways in which they interact with each other and the relevant elements of the environment to create "information technology" than we have in the past.

In this paper we make a first step in that direction by following the evolution of the concept of information in the MIS field and in related disciplines from which we inherited our views, and by suggesting a definition that can satisfy the demands of current research in the area. We then discuss a behaviorally and organizationally motivated definition of information technology and how it can be linked to the traditional MIS view and to other related reference disciplines. We propose a characterization of information technology and illustrate how this characterization can be used to operationalize the concept. Finally, we discuss how past research in information systems complements our definitional framework and the new insights that can be derived from it.

2. What is Information?

Although the concept of "information" can be traced back as early as the fifteenth century (see [16]), it began to acquire its current meaning as something that could be "symbolized, unitized, stored, and processed as a separate entity" only at the beginning of the twentieth century [16], through such works as Frederick W. Taylor's *Principles of Scientific Management* (1911) and Carl C. Parson's *Office Organization and Management* (1918). Since then, the concept of information has undergone significant evolution, and it has become an integral part of several fields ranging from statistical mechanics to cognitive psychology.

At this point we shall briefly contrast four evolutionary perspectives on information, which have influenced the perception of the concept by MIS researchers:

- Shannon viewed information as a quantifiable entity providing an encoding of the state of the world, one occurring from a set of possible states [21]. He focused on the product of different encoding schemes, and the ways this product could be manipulated without losing its validity (i.e., its correspondence to the state of the world from which it originated).

- Von Neumann and Morgenstern extended Shannon's paradigm by introducing a rudimentary value system, in the form of a utility function. They viewed information as determining the preferences among different states of the world, in the context of an adversarial game between two utility-maximizing opponents, and they recognized its importance in providing improved knowledge about the choices faced by the players [26].

- Savage elaborated on von Neumann and Morgenstern's paradigm by considering a probabilistic world, in which a utility-maximizing individual is playing a game against nature. He viewed information as a change in the conditional probabilities of the player. Information affects expected utility by changing the player's assessment of the expected value of his actions in a stochastic environment [20].

- Wiener emphasized the need to look at information as part of a *cybernetic system*: an actor with *goals* reacting through his *effectors* to the state of the external world as perceived by his *sensors*, to eliminate the difference between actual and desired states of the world as measured by his *error detectors* [27]. In this context information is subjective, provoking a (possibly null or *status-quo*-preserving) reaction to changes in the environment.

It can be argued that the first three of the above paradigms have been underlying most mainstream MIS research. In Shannon's view, information is seen in a context devoid of values or semantics. This paradigm has been implicit in most technologically-based work, usually with a computer science or information

theory orientation and a focus on systems design. Von Neumann and Morgenstern's world is essentially deterministic, the choices facing a decision-maker are known, and information is valuable because it can provide an assessment of the utility of consequent states of the world. This corresponds to some recent work in which data management plays a central role [17], and the emphasis is placed on the use of information systems to form a more accurate picture of different situations of interest to the decision-maker, thus improving judgments about their respective desirability. Finally, Savage looks at information in a stochastic context. In Savage's world a decision-maker is concerned with determining the likelihood that different outcomes will result if he takes a given course of action. This view is reflected in work which looks at decision support technology as enhancing the understanding of the consequences of actions, for example with the aid of "what-if" analysis.

While these perspectives have strong mathematical foundations, they offer weaker descriptions of behavior as they pay no attention to the distinction between data and information, and to the human limitations related to the need to comprehend and use this information. This can sometimes lead to questionable or inappropriate results, such as the notion following from Blackwell's theorem* that more detailed information is always better, which has been contradicted by practical evidence [1, 5]. Ackoff was among the first to caution against separating information from the decision-making context, and pointed to the dangers of information overload [1]. We thus believe that MIS researchers should recognize the importance of a broader view of information that does not isolate the "data" from its contextual *structure* and *value systems*, essentially a view corresponding to Wiener's cybernetic paradigm.

Mason and Mitroff, in their influential 1973 article [17], laid a foundation for a good deal of research in MIS during the last decade. That article represented a

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* Blackwell's theorem [6] states in casual terms that detailed information is always at least as valuable as aggregate information derived from the same set of data.

move toward a more sophisticated definition of information by emphasizing the concept of *inquiry.* The authors observed that philosophers had long realized the importance of the semantic component of information, because inquiry, involving the manipulation of both data and their associated semantic structures, cannot take place without it. The primary distinction among their inquiring systems lies in the manner in which they manipulate semantic structures during the inquiry process. Mason and Mitroff claim that the selection of the inquiry system employed, which presumably can be seen as a value-driven choice, is of particular importance. Thus they go beyond the information-theoretic views of information, which implicitly assume that all individuals share the same semantic and value systems.

Throughout the evolution of the concept of information, its distinguishing characteristic has been its role in describing the state of the world, past, present and future. A set of full information should encompass a complete description of the state of the relevant part of the world. The complexity of our physical world makes the transient encoding (i.e. the encoding for temporary use) of such descriptions unrealistic, except for severely restricted situations. To alleviate this problem humans employ models, explicit or implicit, which allow different individuals to share a large part of their view of the world. Specifically, models predetermine a large part of these views, leaving open the values of a relatively small set of parameters. Individuals sharing such parameterized models need to specify only a partial description of the world, in the form of a set of values for the open parameters in those models. Examples of this model-sharing abound, ranging from the linguistic definitions we all share to philosophers' claims that we can only perceive what we already know (i.e. have a model for); it can thus be argued that these models make it possible for us to perceive, use and communicate information.

We refer to information without an underlying model as "data"; the distinction between data and information is the defining characteristic of intelligent systems. Data by itself cannot carry information, as anyone overhearing a

telephone conversation in an unknown language will soon discover. This notion has actually led some linguists to posit the necessity for innate universals that provide a starting point for making sense of the surrounding world and for communicating with other individuals [7]. The process of model-sharing can be observed in every aspect of human intellect from the sharing of innate grammars for linguistic constructs (Chomsky, [7]) to organizational culture (Cyert and March, [8]) to the development of frame-based theories in Artificial Intelligence (Minsky, [18]). Understanding and matching the richness and complexity of models shared by humans has proved a major challenge for researchers in these fields.

While models adequately capture the semantic *structure* of information, their implications for action require a system of *values*. It can be argued that separating value systems from structural models is unnecessary for information systems research since knowledge about the value systems of other information providers can be incorporated in the models of a decision-maker, for example by filtering information according to its source, and since concerns about an individual's own values are usually beyond the scope of MIS. Without claiming to have resolved this issue, in the rest of this paper we will view information as *data plus a context-providing model.*

We believe that inadequate attention to the model-oriented part of information has caused some difficulties in information systems research. Our definition above of information provides the basis for linking information technology to the behavioral and organizational disciplines through the concept of bounded rationality. It suggests that data has no value unless put in the context of the appropriate models, a process taxing the human capacities to communicate, memorize and process information, and thus leading to *bounded rationality*, which is a central concept in organizational behavior theory. The insights resulting from this approach will therefore help us integrate the mathematics/computer science concept of information with the corresponding management accounting concept and the organizational behavior view of the

world. Furthermore they will assist us in comprehending managerial information problems, which are often model-related.

3. What is Information Technology?

Perrow [19] defined *technology* as *systems for getting the work done.* In that context, technology is a structural variable, describing the way organizational resources are managed. Economics have long characterized these resources in terms of the factors of production they employ (capital or labor), and more recently in terms of the function they perform (they *store*, *transport* or *transform* raw or processed materials), and the structure of the system, referred to as the type of technology. Thompson [25] identified three basic types of technology corresponding to generic ways to combine resources during system design: sequential (single input, single output components), intensive (multiple input, single output components), and mediating (multiple input, multiple output components). Mason [15] completed this classification by adding one more category, extensive technology (single input, multiple output).

Following this line of thinking, information has been treated as both a factor of production and as an input to the production process, from a macroeconomic [12], and a microeconomic [24] point of view. This corresponds to what can be considered as the traditional definition of information technology:

> Information technology is the set of non-human resources dedicated to the storage, processing and communication of information, and the way in which these resources are organized into a system capable to perform a set of tasks.

This definition, by treating information similarly to other inputs in the production process and information technology as just another form of capital investment, employs a view of information analogous to Shannon's paradigm. For example no distinction is made between models and data, and information technology is not differentiated from other process technologies except to the extent that it is manipulating a different resource (information). This

perspective has been implicit in most research with a computer science, industrial engineering, or operations research orientation. It may correspond well enough to traditional transaction-processing systems, but it would probably prove inadequate to study systems with more complex organizational impacts, such as the several applications that constitute end-user computing.

We believe that the concept of *bounded rationality* provides an important link between organizational and behavioral theories and information technology. At the individual level, rationality can be described as the reaction of an individual to information about changes in the state of the world demonstrating a set of goals, in correspondence to Wiener's cybernetic paradigm [27]. Bounded rationality refers to neurophysiological limits on memory, computational, and communication capacities of an individual [22, 23]. It is demonstrated by limits on the complexity and size of problems that can be solved by humans. Both concepts of rationality and bounded rationality can be extended to the organizational level, and bounded rationality has been an important concept in organizational design [8, 10, 14, 28].

Building on Perrow's concept of technology and taking into consideration the organizational issues discussed above, we are led to a definition of information technology that is behaviorally and organizationally motivated and spans both approaches. First, information can be viewed as a factor of production, and hence information technology assumes its traditional role of a process technology: the utilization of resources devoted to handling and processing of information. Second, information is an important component of an organization's environment and is intimately related to organizational rationality. Thus information technology can have a significant impact on the bounds of organizational rationality. The following definition of information technology captures both perspectives:

> Information technology encompasses systems that affect the bounds in the rationality of organizational units and the limitations of their information-related process technology. These bounds and limitations may be either internally imposed (because of human

neurophysiological limitations) or external (because of technological design limitations).

We have proposed here a definition of information technology that recognizes its dual role: that of an *organization* technology affecting the bounds of organizational rationality, and that of a *process* technology, devoted to the handling and processing of information. We believe that many past problems in information systems research were caused by attempting to address issues related to organizational rationality while adopting a perspective limited to a process view of information technology.

Occasionally the distinction between these two roles of information technology becomes blurred, as they are not orthogonal. However, if we insist on specifying a dominant role of information technology from the MIS perspective, we believe its role as an organization technology to be the more appropriate one. Technologies that are primarily process-oriented (e.g., robotics, optical character readers, etc.) are usually of marginal interest to MIS, except to the extent that they can affect organizational rationality, usually by providing information not accessible otherwise.

Keen claimed that a major factor limiting MIS research is the lack of appropriate reference disciplines [13]. Our definition of information technology has important implications for the choice of these disciplines. Information theory, systems design and computer science have long been the foundation of the traditional view of information technology and they hardly need further justification. Theories of human information processing and decision making, and thus cognitive psychology have long been used as implicit reference theories, and they are relevant to our view of models as an important constituent of information, as well as our emphasis on bounded rationality. In view of our discussion on the relation between information technology and organizational rationality, organization design theories are an important discipline to *define and describe* information technology, as well as to study its organizational implications.

Information technology is not an end in itself, it is used instead as a means to achieve organizational goals. Thus it becomes significant only in the context of specific organizational settings. Depending on the relevant application scenarios, other reference disciplines become appropriate. For example, to understand the potential of information technology as a strategic business factor, corporate strategy and industrial economics come in as relevant disciplines [4]. These disciplines offer generally acceptable *reference theories*, e.g., a theory of the elements of corporate strategy, or of the forces creating competitive advantage. These theories can be related to others from the MIS discipline (e.g., a taxonomy and characterization of the elements of information technology), to develop new theories in the area of interest (e.g., about the types of information systems appropriate under different competitive scenarios). As Keen has observed [13], this interdisciplinary cross-fertilization is extremely valuable. Idiosyncratic theories developed for a specific purpose usually cannot compete in quality with the well developed general theories in the relevant reference disciplines; when MIS researchers develop theories promoting advances in other established disciplines, they should be recognized as making an original contribution to these disciplines.

Under these circumstances, the value of a powerful definition of information technology is easier to see. It allows us to "marry" information systems and organization theory, e.g., taking advantage of the fact that both fields talk about storage, processing and communication of information. It also allows us to build better models, based on appropriate general theories, that will help us meet the logico-deductive criteria for the validation of rigorous research [2]. The investment in a more precise language and definitions pays off by allowing us to develop testable hypotheses and by facilitating the operationalization of our constructs.

4. A Characterization of Information Technology

There are two pertinent dimensions that allow us to characterize (and thus compare) different technologies: functionality and capability. Traditional definitions proposed by Perrow [19], Thompson [25], and others promote a network paradigm of technology, with nodes that store or transform material resources and edges that provide for their transportation. Hence storage, transformation and transportation are the constituents underlying the functionality of a given technology.

Technological capabilities can be described in terms of output capacity, that is the ability to achieve a certain performance benchmark, and cost, that is alternative economically valuable uses of the resources consumed. These capabilities define a "technological frontier," typically described by a tradeoff between cost and performance. The maximum performance achievable at any feasible cost is often a parameter of this tradeoff warranting special interest.

In the case of information technology, a computer science (information theoretic) perspective would suggest that the relevant characteristics corresponding to the functionality dimension are *storage*, *processing* and *communication*. Behavioral theory is consistent with this view, as it sees bounded rationality to be arising from limitations in the human ability to store, process and communicate information. This distinction is also consistent with organization theory and the organizational rationality view of information technology: while engaged in organizational problem solving, individuals acquire and process information and communicate the results of this processing to other agents in the organization or its environment This congruence of views is to be expected, since all three of the above perspectives start from the same paradigm of technology to describe systems, humans and organizations.

There are three characteristics of information technology underlying the capability dimension: *capacity*, *quality* and *cost*. Capacity refers to the ability to

store, process and transmit large quantities of information in a given time interval. Quality refers to the ability to preserve the accuracy of information, i.e., the degree of correspondence between "reality" and its representation in terms of data and models (i.e., information). Capacity and quality determine the performance of a system based on information technology. These perspectives are motivated both from an information theoretic (or computer science) perspective, in which quality can be seen as the resistance of the system to errors while capacity refers to its ability to meet certain benchmarks, and from a behavioral and organizational perspective, in which imperfect information (quality) and limited resources (capacity) are the factors preventing "perfect" rationality. Finally, cost refers to the employment of resources of alternative value (economic, social, or otherwise).

Thus we are led to a three by three matrix characterizing information technology, which is shown in the Figure. The entries in the nine slots are not specified, because different disciplines are likely to employ different specific characterizations of information technology. For example, quality of communication for an information theorist could refer to the noiseless transmission of an information signal, while to a behavioral scientist quality of communication may include the match between reality and its representation (modeling error), or even focus on interpretation (value systems). Similarly, cost may have different meanings for a systems researcher (looking at economic cost) and a labor relations analyst (looking at social cost).

An interesting implication of this variety of perspectives is that different disciplines will focus on different areas in the characterization matrix. For example, Galbraith's information processing view of organizations [9, 10] posits that as environmental uncertainty and complexity increase, organizations must cope by either increasing their information processing capacity or by decreasing their information processing requirements. Galbraith's view of information technology would thus focus on processing and communications capacity (areas

	Storage	Processing	Communications
Capacity	1	2	3
Quality	4	5	6
Cost	7	8	9

Figure: A characterization of information technology

(2) and (3) in our matrix), with a secondary emphasis on their quality (areas (5) and (6) in our matrix).

An alternative perspective on organizations is provided by Williamson's transaction cost approach [28]. Williamson asserts that constraints on human information processing are a major reason for the very existence of organizations. An alternative to organizations is to have economic agents act independently and contract to sell their services to one another in a marketplace. With unbounded rationality, every participant could counteract the effect of other participants' deceptive, self-interested behavior. In a world of bounded rationality, however, such opportunistic behavior in small marketplaces creates inefficiencies in the form of excessive contracting and transaction costs. To avoid these costs, individuals form organizations in which interests are pooled. Hence

interfaces between information processing subsystems are not frictionless, and this perspective would imply an emphasis on the cost-related elements of information technology (areas (7), (8) and (9) in our matrix).

Other approaches emphasize the role of organizational rules and procedures, which are seen as a form of organizational memory (e.g., [8]). These perspectives would pay particular attention to the ability of information technology to affect the capacity and quality of organizational storage of information, and especially its model-related components (areas (1) and (4) in our matrix). An important implication of these differences in focus is that *different operationalizations of technology will be appropriate for different research disciplines.*

The ability of our characterization to *compare and contrast different systems* can be quite valuable as well. For example, applied over a time period, it can be used to support paradigms for the evolution of information systems. Thus the existence of a general trend in the technology toward integration across the three basic functionality dimensions can be argued, as evidenced by developments such as decision support systems integrating modeling with data management, the emergence of PBXs with voice-mail and data switching capabilities, and as demonstrated by the debate over the boundaries of processing and communication in public carrier networks.

5. Concluding Remarks

The definition and characterization of information technology presented in this paper complements and extends the prominent research paradigms in MIS, such as those of Mason and Mitroff [17], or Ives, Hamilton and Davis [11]. This fit is not surprising, since we have verbalized a perception of systems and organizations based on bounded rationality, which originated from Simon's work and the information processing view of organizations, and which we believe to have been implicit in the thinking of most MIS researchers.

On the other hand, externalizing this paradigm in a systematic manner provides a number of concrete benefits: it points out the salient characteristics of information technology, hence it allows us to compare and contrast different systems, and enhances our ability to generalize results across different studies. It is useful in identifying the pertinent characteristics of information technology in different theoretical contexts; thus it facilitates the operationalization of variables related to information technology, and it can help make possible the testing of corresponding theories. Finally, our definition of information technology, by emphasizing its behavioral and organizational as well as its information theoretic aspects, promotes the development of a coherent reference discipline for MIS research, which will include appropriate reference theories from related disciplines such as computer science and organizational behavior.

It is likely, however, that even this approach will eventually prove inadequate to tackle certain organizational and behavioral issues of interest to MIS researchers. If this is the case, it may be an indication that we are approaching the limits of the descriptive and explanatory power of the bounded rationality model, at least as far as ground-breaking insights are concerned. Extending the scope of such a powerful paradigm is a very ambitious and challenging undertaking. An interesting notion of possible value is that of *value systems* as a component of information beyond data and models, a notion implicit in Churchman's types of inquiry systems that underlie Mason and Mitroff's framework. Given the scope of this paper, we have barely touched at this issue in section two, yet it could be a promising direction for future inquiry.

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